The NIST Design/Process Planning Integration Project

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Abstract

This paper presents a description of the National Institute of Standards and Technology (NIST) Design/Process Planning Integration (DPPI) Project, which addresses the need for improving communications between design and process planning activities. Specifically, we focus on the early phases of design and our efforts to link conceptual design ideas to corresponding ones in process planning. After describing the project goals and the mechanisms to achieve those goals, we review representative Computer-Aided Design (CAD) and Computer-Aided Process Planning (CAPP) software tools. The review reveals the lack of available design and process planning tool integration, especially at the conceptual level. To begin our development of an information model suitable for integrating design and process planning knowledge, we developed a prototype conceptual design of a planetary gearbox. At the conceptual level, we associate several design issues with process planning ones and show that these issues can be related in a meaningful way, even at the conceptual level. We conclude that developing associations between design and process planning is meaningful and can be integrated to improve the way engineers design products.

Introduction

Experienced designers often are able to create successful initial designs because of their years of design experience and their acquired knowledge of manufacturing processes. However, less experienced designers often require input from experienced personnel in both the design sector and the manufacturing sector. Ideally, the novice designer should be able to get manufacturing, design, cost estimation, and process planning input at all stages of design to aid in the design process. This can be burdensome to the rest of the personnel.

With the advent of Computer-Aided Design (CAD), designers can do a large amount of design work using advanced computer modeling tools such as finite element analysis, solid geometric modeling, and kinematics/dynamic analysis. On the manufacturing side, Computer-Aided Process Planning (CAPP) software enables manufacturing personnel to create process plans and get manufacturing cost estimations with the aid of a computer.

Normally, the early design stages (i.e. conceptual design and embodiment design) determine most of product cost and manufacturing methods. Although CAD and CAPP can significantly improve detailed design and detailed manufacturing methods, respectively, they do not do so collectively, and they do not function well at the conceptual level. Hence, it is up to the designer to create practical conceptual designs that are easy to manufacture. Currently, design engineers are being trained to design products with manufacturability (Dixon and Poli 1995) and assembly (Boothroyd and Dewhurst 1983) in mind. However, design engineers cannot be expected to know everything about these subjects and also be experts in their own domain.

Therefore, to improve a product during the entire design phase, the designer should have process planning, cost estimation, and design tools that all work together. This would enable the designer to make more sound judgements throughout product design. Since most CAPP and CAD systems are based on proprietary software, a standard for creating interoperability between different CAx (Computer-Aided) systems should be created. STEP (Standard for the Exchange of Product Model Data) addresses many of these interoperability issues (ISO 10303, 1994); however, STEP focuses primarily on geometry at the detailed stages of design and manufacturing. At NIST, interoperability limitations among disparate design systems and systems outside of the design spectrum are being studied to extend the capabilities of STEP and other standards (Sriram 1996).

This paper describes one of these efforts, the NIST Design/Process Planning Integration (DPPI) Project. This project addresses need for an information model to improve communication between design and process planning at all steps in the product design. The following sections describe the current state-of-the-art in design and process planning software, the objective of the project, and the current state of the project. An example, a gearbox, is being used to create an initial information model during the initial stages of the project; this example is also described in the paper.

Design and Process Planning Software

Both process planning and design take place at many different levels (Barkmeyer 1996). The design phase includes several stages: creation of specifications, development of conceptual designs, and development of detailed designs (see Figure 1). Specifications are developed early in the design phase to communicate the necessary characteristics of a product. At the conceptual design phase, initial design ideas are created. These ideas can include sketches of a preliminary product layout and straw-man concepts. Finally, the detailed design phase includes the detailed assembly and part drawings/models.

Currently, most software packages that aid an engineer during product design focus on analysis or detailed geometry generation. The systems that deal with geometry are now using parametric and feature-based design methods (Shah and Mantyla 1995); however, this still requires the design to be almost completely formalized. Systems have also been developed that allow routine design tasks to be automated. A designer can program knowledge into these systems to automatically generate a design using various input parameters. Knowledge Technologies' ICAD and TechnoSoft's AML are examples of these knowledge-based systems. Programs have also been developed that allow kinematics/dynamic analysis of complex mechanical systems (for example, Working Model).

Although these systems can help a designer during the conceptual design stage, they do not address many important aspects of conceptual design including functional decomposition. Academic researchers have been working on the conceptual design problem since the early 1980s, creating several different synthesis systems. One such system, CONGEN (CONcept GENerator), is a domain-independent knowledge-based system framework that maps an evolving symbolic description of a design into a geometric one (Gorti and Sriram 1996). This system and others like it, including ICAD and AML, are being evaluated for possible use in this project.

Process planning also is an evolving process where conceptual process plans grow into detailed process plans (see Figure 1). Conceptual process planning may involve the selection of the most suitable technologies (e.g., metal removal, material addition, forming, and joining) and materials for producing a feature, a part, or a product (ElMaraghy 1993). Additional conceptual process planning outcomes include manufacturability feedback, initial assembly analysis results, and preliminary cost estimations. Detailed process planning develops the necessary sequence of operations to produce a part from stock material. In addition, detailed process plans may also include a detailed cost estimation. This gives the manufacturer an understanding of the costs involved prior to starting the actual manufacturing process.

Similar to design software, process planning software has been developed for use at the detailed stage. Commercial process planning software requires complete design geometry in order to deliver process plans and cost estimations. Moreover, these systems focus on a particular type of manufacturing such as machining. Hence, they will not suggest a better manufacturing process outside of their domain.

Academic researchers have also been looking into the conceptual process planning and cost estimation problem. Several systems have been created for preliminary cost estimation. For example, Ou-Yang and Lin (1997) developed a preliminary cost estimator for machining, and Mileham et al. (1993) developed a similar system for injection molded parts. Preliminary manufacturability systems have been developed for various tasks including electronic product development (Harkalakis et al. 1993), welding (Yao, Bradley, and Maropoulos 1998), and stamped metal parts (Mukherjee and Liu 1997). Material and process selection issues have also been addressed by researchers (e.g., Giachetti 1998 and Cogun 1994).

DPPI Project Objectives

The NIST Design/Process Planning Integration (DPPI) Project is an ongoing multi-year project with the objective of developing an information model to enable design and process planning software to communicate during all stages of design. Information that needs to be sent includes data and knowledge such as material parameters or specific materials, catalog parts that could be used in the product, assembly relations, tolerances, part geometry, process specifications, and design rationale.

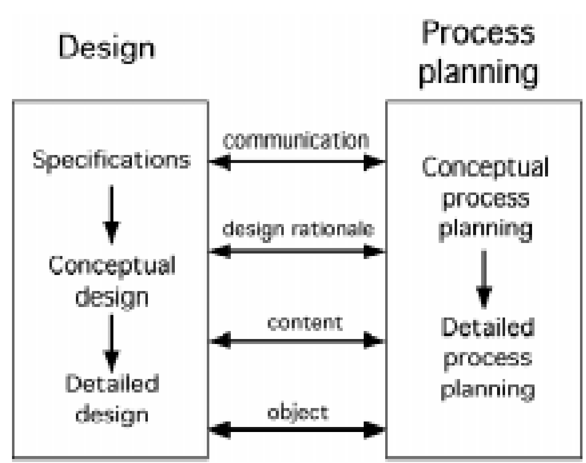

Figure 1: Communication between design and process

planning

Design/process planning integration needs to take place on many different layers (see Figure 1). These layers include items such as content, design rationale, and communication. At the content layer, engineering details such as features, constraints, geometry, and processes are stored. The design rationale layer covers issues such as design history, plans, and goals. Finally, the communication layer provides communication primitives and protocols (see, for example, Allada, Feng, and Ray 1997 and Cutkosky et al. 1993).

The content layer and design rationale layer are commonly structured using an object-oriented framework. Wong and Sriram (1993) developed an advanced object-oriented framework for storing product and design processes. This framework allows for multiple versions of parts; relationships between function, form, and behavior for each part; part attributes; constraints; and assembly relationships. The DPPI project is using this framework for development of an example to better understand the requirements for the final information model.

Current State of the project

Development of an information model that can hold all of the necessary data and knowledge for a complex design is a difficult problem. Hence, after completing a literature survey and a survey of relevant commercial software, we decided to study a limited problem that would aid us in understanding the whole problem. We also decided to start the project with a focus on conceptual design and conceptual process planning due to the need for better communications at this level. Therefore, using and extending existing information models and software packages, we are concentrating on a sample design to bring the project dimensions into focus.

The sample design needed to be complex enough to require manufacturing feedback, but simple enough that everyone on the project would understand the issues involved in the design. We decided to use a gearbox.

We began our study of the gearbox by considering the possible specifications that designers could anticipate from management in a typical environment. These specifications included items such as speed/torque requirements, input and output shaft locations, quantity needed, design and manufacturing time constraints, weight restrictions, aesthetics, environmental constraints, and size limitations. These specifications, by themselves, should be sent to a conceptual process planning system for analysis because much manufacturing feedback can be gained at this point. For example, the quantity can dictate the most appropriate manufacturing processes, and aesthetics may limit materials, processes, and coatings. Using the object-oriented framework developed by Wong and Sriram (1993), these specification constraints and attributes were stored for the gearbox design.
Using these specifications, we developed a functional decomposition of our gearbox, and we used this decomposition to create various alternative conceptual models. Again, we stored all of this information in an object-oriented framework. To limit the complexity of this design problem, we focussed on a planetary gearbox system. A drawing of the preliminary assembly for the gearbox is shown in Figure 2.

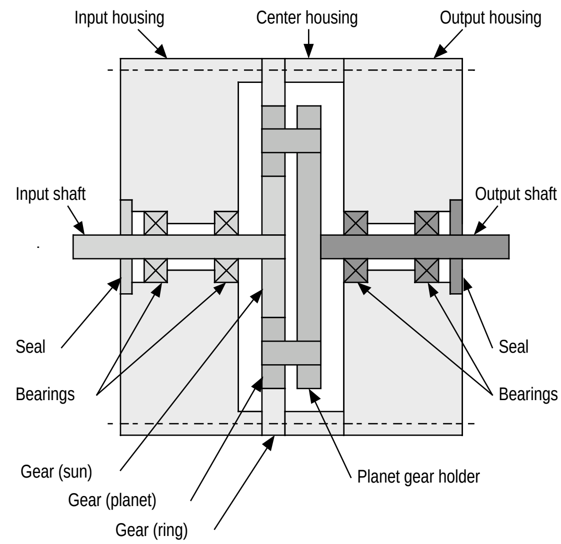

Figure 2: A planetary gearbox

To implement our model, we are currently developing a conceptual process planning system, using AML, and a conceptual gearbox design system, using ICAD. The conceptual gearbox design system accepts multiple attributes, parameters, and constraints as input, and it creates several different conceptual gearbox models based on this input. The conceptual process planner allows different part characteristics as input such as material, general shape descriptions, quantity needed, approximate size, and surface roughness; and it returns the best manufacturing processes for the given conditions. Figure 3 shows the graphical user interface for our current conceptual process planning system.

During development of our gearbox design system, we found that there are many issues that arise during the design where it is beneficial to receive some manufacturing feedback. For example, a designer could choose different exterior shapes for the gearbox such as a square-face gearbox and a circular-face gearbox (see Figure 4). Both shapes may meet the design specifications; however, the designs have different manufacturing requirements. For example, using machining operations, a square housing will be more difficult to make on a lathe, while a round housing will be more difficult to make on a mill. Therefore, one design is preferred over the other from a manufacturing viewpoint because of ease of production, reduction in manufacturing time, cost, availability of material, and the manufacturing plant capability.

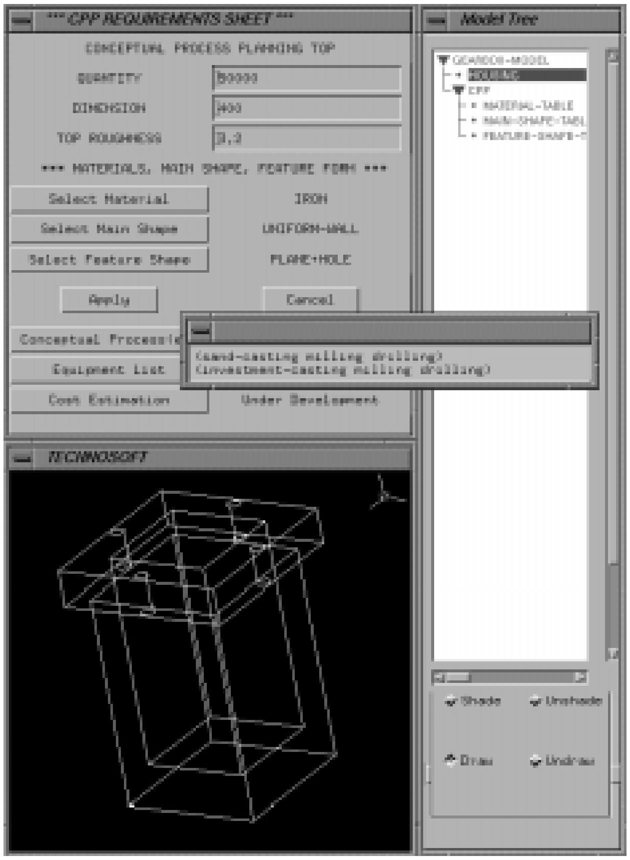

Figure 3: Graphical user interface for our current conceptual process planning system

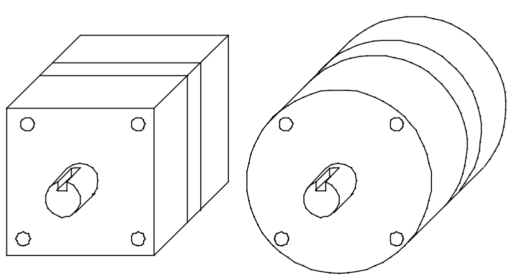

Figure 4: A square-face gearbox versus a circular-face gearbox

Another example where manufacturing feedback is desirable is shown in Figure 5. This figure illustrates two different ways of designing the planet holder in a planetary gearbox. One design encompasses the output shaft and the other design does not. From a manufacturing and assembly point, one of these designs is better, but which one? Moreover, if the separate-shaft design is more desirable, then how is the shaft going to be attached to the planetary gearbox? By welding? By a keyway and retainer rings? Again, this will depend on design and manufacturing insight.

These are just a few of the manufacturing questions that arise during the conceptual design of a simple planetary gearbox. Hence, this should illustrate the need for a system that can help a designer with manufacturing feedback, and the need for an information model for sending the design information to this system.

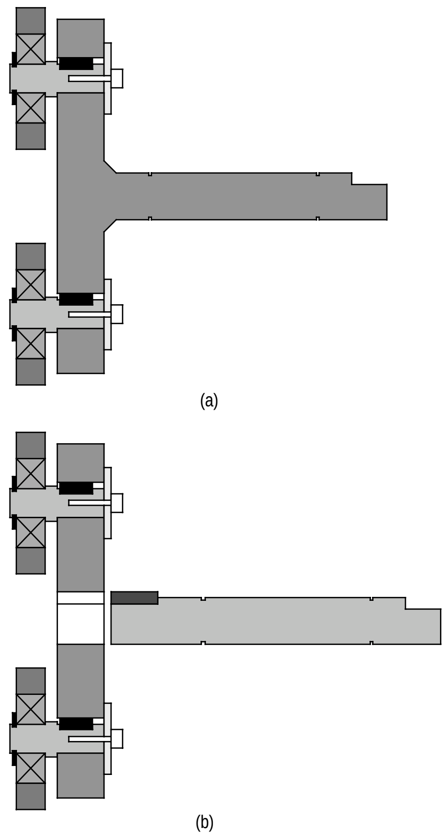

Figure 5: Two planet holder designs

Conclusions and Future Directions

In this paper, we discussed the need for an information model for communicating between design and process planning. We also described the NIST Design/Process Planning Project, which is addressing this very issue. During this description, the development of a limited information model for a specific case, a planetary gearbox, was discussed. This simple, yet representative, example is just the starting point for a much more elaborate information model.

Soon we will create an interface between our conceptual gearbox design system and our conceptual process planning system that will allow our information model to be passed between them. We also will expand both systems to encompass more design and manufacturing knowledge.

After completion of the gearbox model, we will present our case to industry via technical papers and workshops. We hope to receive valuable input from industry on what they want and need in the information model. We also hope to work with industry to encourage the development commercial software that can handle more conceptual modeling.

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Disclaimer

Certain software products are identified in this paper. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products identified are necessarily the best available for the purpose.

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